USAF INSTRUMENT PILOT INSTRUCTOR SCHOOL

Randolph Air Force Base, Texas

CONTROL-DISPLAY INTEGRATION PROGRAM

CREW DUTIES, MODE AND FUNCTION STUDY

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Some of the basic problems associated with low visibility approaches can be traced to doubts concerning piloting roles when operating to lower minimums. Somewhat dependent on piloting procedures are the avionics and mode selection configurations which will not only integrate man and automatics, but provide the apparatus for control monitoring and decision making. It is quite correct that an autopilot is an extremely important systems component. However, an autopilot in itself will not fulfill piloting requirements. What if the autopilot fails or softens in an axis? The crew must be prepared to take over the failed or softened component. This will only be possible if an adequate man machine interface has been accomplished.

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FOREWORD

The role of pilots during low visibility approaches and landings requires considerable thought relating to both the crew procedures to be employed and the interface of the pilots with the aircraft. This technical note documents the crew procedures attitudes of project pilots who made several hundred instrument approaches in weather conditions to and including "zero-zero". This report is directed toward establishing the rationale for crew procedures and man/machine interface.

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This technical note has been reviewed and is approved.

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SECTION I

INTRODUCTION

This technical note was derived from pilot experiences obtained during low visibility approaches performed in the Landing Weather Minimums Investigation. A number of questions such as the role of the pilot, crew procedures, low visibility transition problems, weather environments and pilot/aircraft interface were encountered which had not been specifically addressed, except in theory, prior to actual inflight research in a low visibility environment. A lot of opinion had been expressed on the above topics, but little from the meaningful standpoint of a pilot who had experienced first-hand the physiological or psychological aspects of operating in such a hostile environment. The objectives of this technical note are to pass on to the reader first-hand piloting experiences of:

a. Requirements for maintaining the pilot as an active control element within the autopilot loop.

b. Transitional problems which are encountered in the low visibility environment.

c The different types of weather categories and problems of operating in each.

d. Crew procedures requirements.

e. Pilot interface requirements for operating in low visibility conditions.

<u>Low Visibility Considerations</u>

One of the objectives of the Landing Weather Minimums Investigation (LWMI) was to develop crew procedures and suggest control display configurations for low visibility landings. Over 300 low visibility landings were made and as experience was gained, guidelines for crew procedures and pilot interface began to appear due to the influence of the low visibility environment on piloting tasks. Some important realizations which occurred were:

a. The visibilities caused by fog were usually greater than Category I (200 feet DH and 1/2 mile visibility) or less than Category IIIA (700 feet RVR) meaning that the theoretical Category II operation seldom, if ever, existed.

b. Visual information is usually available from the approach lighting system and runway environment even though the weather is reported as zero-zero.

c. Pilots could use visual segments of 600 feet to maintain lateral alignment, but had insufficient visual information to flare.

d. The low visibility environment can present confusing and illusionary information.

e. At least three seconds were required for a pilot to orient himself in visibilities between 600 and 900 feet if a sudden transition were made to visual flight.

f. A visual segment of 600 feet was sufficient for rollout, using cues from either centerline lights or markings.

SECTION II

PILOT IN THE LOOP

One basic problem of low visibility landings rests with the assigned role(s) of the pilot(s) and a lack of knowledge and understanding of what the pilot should or should not attempt to do in the low visibility environment. For example, in order for a pilot to use the visual information that may be available during an approach, he must have the training to use the information. If not, the visual information may be misinterpreted with catastrophic results.

Also, the pilot's assigned role must be clearly defined to add some substance to the development of crew stations configurations -- and assignment of proper procedures during the approach. Some designers stress the need for completely automated approach and landing; others see a need for the pilot in the control loop during approach and landing. Regardless of the level of automaticity, the pilot will be the ultimate decision maker in the man/machine relationship, as long as aircraft are manned. Therefore, he must be provided adequate means to evaluate systems performance and take corrective action when required. The basic necessity for the judgment and adaptive characteristics of the pilot, and his responsibility for the safe conduct of flig . requires the pilot to be involved during the low visibility approach and landing

The pilot's role during visual or Category I conditions is relatively facile. During visual conditions, pilots use a form of composite control: visual information supplemented with performance information from the engine and flight instruments. In Category I weather and better, pilots are able to use instrument information until they break out of an overcast, and then safely transition to composite flight to complete the approach and landing. The two weather conditions which produce doubt about the pilot's role are the zero-zero visibility landing and the "quasi" condition where visual information is insufficient to effect the composite flight mentioned before. However, if adequate instrument information is available within the cockpit, how can this information best be used for the low visibility and zero-zero landing? Will the pilot(s) be provided access into the control system to assist the automatics with aircraft control or will the pilot(s) serve as monitors with the assigned task to take over only if an emergency occurs?

During project flying in low visibility, all participating pilots agreed that it is absolutely essential that pilots be provided access into the automatic system. They felt that only by being integrated as an active control element will they be psychologically and physically prepared to assist or assume active command. To participate in the control loop requires that the following criteria be satisfied: the pilot must have some type of force wheel steering to assist the autopilot; the computer which drives the autopilot must also drive the command steering information so that the pilot can continuously assess autopilot performance and finally, the pilot must have the instrument displays to effect a manual (without autopilot assistance) on-instruments approach, flare, touchdown and rollout.

The next question which arises is the procedural use of the control/display system. The procedural question may be examined in terms of the transitional problems which may occur on short final during a low visibility approach.

Transitional Problems

If an aircraft can be flown throughout its entire flight profile without outside visual references, then the real world is not necessary, since all piloting tasks can be performed with reference to instrumentation within the aircraft. This implies instrumentation of a very sophisticated nature, to relate to the pilot all the information he needs to determine aircraft position with respect to the runway, plus guidance, command and performance information. However, information relating aircraft position to the runway is still lacking a most important ingredient, i.e., predictive position. Predictive information is an integral part of an optimum display which should indicate the aircraft will arrive on the runway in the proper attitude at a given time.

Presently the pilot is faced with using parameters which do not allow him to maneuver or determine his position with respect to the runway. He can determine he is left or right of a radio course, but must rely on the acuity of visual information at a specified decision height to complete the approach and landing. In the low visibility environment, present instrument displays are adequate to maintain instrument flight to a decision height of 100 feet with approximately 1600 feet RVR. For precision flying, however, present instruments

do not display information adequate enough to enable the subtle corrections necessary in visibilities below 1600 feet.

Therefore, a pilot's capability to maintain instrument flight begins to deteriorate when descending through a height of 200 feet since the displayed information does not relate to the runway centerline nor provide the means for the finite corrections required. Thus, supplemental information relating to flight path control must be derived from outside the cockpit at some altitude below 200 feet. This is extremely undesirable in adverse weather conditions since the pilot must divide his attention between instrument displays and visual information from the real world. Almost certainly the pilot will place more emphasis on real-world cues which may not relate an accurate picture of approach progress, and in some cases create false illusions.

Presently it is audacious for a pilot to maintain instrument flight to touchdown. The process is one of supplementing instrument with visual information until there is enough visual information to ascertain lateral alignment with the runway. Then the longitudinal axis receives a pilot's attention until there are enough cues to flare the aircraft visually.

When a pilot is performing a visual landing, he can gauge his rate of closure with the touchdown point and has at his disposal all the information he needs to effect the finite roll, pitch, yaw and airspeed corrections necessary for a successful approach, landing and rollout. If weather obscures the pilot's aiming point, but allows cues for lateral control, he is faced with a form of composite control where instruments must be used to maintain a glide path and flare and a pilot must integrate cues from both the visual and instrument environment. This form of control can be potentially dangerous since the visibility may worsen as in a shallow fog; if this occurs, the approach cannot be safely continued and an extremely hazardous condition may exist.

The "see-to-land" technique entails maintaining instrument flight while attempting to establish visual contact with the runway environment at decision height, or some point thereafter, and then transferring to visual flight to complete the approach and landing. In reality the visibility for a distinct transition from instrument to visual flight seldom, if ever, exists in actual low visibility conditions.

If restrictions to visibility exist, they are usually caused by total or partial obscurations which normally produce visibilities less than 1000 feet. The problem, then, doesn't involve a transition to visual flight, but a method to maintain lateral alignment and flare on instruments. To attempt the transition visually requires 3 to 4 seconds for the pilot to assimilate the visual cues, another second or so to determine a course of action, another second for the control input, after which the aircraft reacts to the control input. If we further examine this piloting task, we may find the pilot is not absolutely positive that the visual patterns developing define the aircraft's attitude and position. It was noted many times during the LWMI that a pilot using outside visual references had the sensation the aircraft was much higher than its actual altitude. This visual illusion could lead to a duck-under maneuver during a critical phase of flight. Another important aspect was the lack of a well-defined aiming point for touchdown. This causes the flare perspective to lack the fundamental characteristics apparent during an unrestricted visual flare. The pilot's visual segment may contain enough cues for lateral alignment; however, the visual perspective to flare the aircraft is lacking. This condition was encountered numerous times in low visibility conditions.

The conditions described above denote a phase of aircraft control which is a combination of both instrument and visual control or partial instrument/visual flight, both being required. This situation develops when there are enough visual cues to provide some guidance, but not enough for total reliance. This condition is perhaps the most dangerous due to the visual illusions, false sensations, lack of well-defined cues, pilot reaction time, and other limitations of the environment. It is this type of partial control, both visual and instrument, which is neither desirable nor tolerable, since there are too few cues from either source to provide accurate information for aircraft control. Also, the pilot is faced with an extremely serious problem if he elects to monitor aircraft position in the low visibility environment with present instruments; since it is difficult to determine autopilot performance or assist with the tracking task.

It is quite obvious the visual flight cannot be maintained for 100% of the approaches, landings and rollouts. Would it then be possible to develop an instrument system capable of displaying the information a pilot needs to maintain instrument flight throughout the approach and landing profile? Also, could such a system be configured to

produce more desirable information than the real world? The answers to these questions will provide the key for the configurations required to have a true low visibility landing capability.

SECTION III

CREW PROCEDURES

Instrument flight in any type of weather environment requires definition of piloting roles if operations are to be efficient. The weather environment will, to some extent, provide guidelines and restrictions to crew procedures and training requirements. If the different types of weather environments are examined, crew procedures may become evident which will be appropriate for all types of visibility conditions. Basically, three types of visibility categories may be encountered - the cloud base ceiling, the zero-zero visibility condition, and the "quasi" condition. Also, it is possible that a combination of these conditions may exist. These three conditions and conceivable combinations will be investigated from the crew procedures viewpoint to determine possible piloting roles. Let us discuss these weather categories and how they affect crew procedures.

The cloud base ceiling can be defined as that meteorological condition where the aircraft descends through a definite ceiling. Once the ceiling is passed, visibility is usually unrestricted. Conditions such as rain, snow, etc., may exist, but there are still sufficient visual references to maintain composite flight, as previously defined. In this type of condition, pilots may use a number of different crew allocations. Some of these could include the co-pilot flying instruments until composite flight is possible and then either continuing visually to touchdown or relinquishing control to the aircraft commander. Another possibility could be the aircraft commander making the instrument approach and either continuing to touchdown or allowing the co-pilot to fly to touchdown once composite flight can be maintained. There could also be a split allocation concept with the pilot not flying instruments controlling the throttles to maintain airspeed. Another possibility could [illegible] split axis concept with one pilot controlling pitch and power wh[illegible]e the other has roll and yaw. Other combinations could also be arranged.

The cloud base ceiling offers no particular stressful challenge since visual references will be plentiful once the ceiling is passed. However, it is possible to enter into the "quasi" condition if

composite flight is not stri. ! · adhered to. If, for example, the approach is conducted at night in an area without many lights or at an austere facility, it is possible the visual references may not be reliable. Even though the entire approach and runway lighting system is in view, pilots have landed short of runways, in some cases up to five miles, simply because the visual references were insufficient for adequate depth perception or created illusions leading to the errors. This could also be the case during approaches in snow, rain, etc., where the visibility is somewhat obscured. The solution to preventing these types of accidents is to maintain composite flight. Also, one pilot, in a dual aircraft, could be tasked to specifically monitor instrumentation. This type of task allocation could possibly prevent premature descents or large excursions from instrument flight paths when the visual references create illusions of false height or present ill-defined cues.

The reported zero-zero weather condition presents a situation where there are supposedly no visual references to control the aircraft. Therefore, at least one pilot must maintain instrument flight to touchdown, throughout rollout and during taxi. The other pilot could be either looking outside for visual cues or assisting passively or actively with instrument flight. The experiences acquired during the LWMI indicate that there may be visual references available even though the visibility is reported as zero. In fact, visibilities as great as 600 feet were noted and usually at least 200 feet visibility was available. These findings indicate that some visual information may be available to assess Category III approach progress. A great deal of caution must be exercised when interpreting and using cues in the low visibility environment. This does not mean these cues can be used for path control, only that visual confirmation of approach progress may be possible. Training will be required to use cues properly in the lower visibilities. The role of the pilots in the zero-zero environment could be to have one pilot maintain instrument flight to touchdown while the other pilot acts as the decision maker, based on the information acquired from the instrument displays, independent landing monitor or visual cues if available.

The "quasi" weather environment provides insufficient information to conduct visual flight although enough cues are available to positively confirm position. The "quasi" environment presents the greatest challenge to crew integrity since there will definitely be

visual cues for interpretation and possible use for lateral alignment and flare. Let us look at the "quasi" environment, approach geometry, and the limitations inherent with cockpit design before discussing crew procedures in this environment.

Generally, the weather associated with the "quasi" environment is fog, which can be categorized as either shallow or deep. In either case the characteristics of each may vary considerably and pilots have no meaningful information relating to them a true picture of the visibility conditions until they actually encounter the weather phenomena. In shallow fog, pilots generally expect to have visual cues until the top of the fog is encountered, then some or all cues may be lost until close to the flare height. In deep fog, (fogs several hundred feet thick) pilots generally expect cues close to decision height unless it's a deep, mature, homogeneous fog. In either case, if the theoretical 1200 foot RVR exists at decision height, the pilot's aiming point and runway threshold will not be in view, although sufficient visual references may be available for lateral alignment. The weather phenomena then dictates a requirement for continued instrument flight past the decision height. Therefore, one pilot must fly instruments while the other continues to evaluate the weather environment with respect to the visual patterns developing.

A second important consideration is the limitation imposed on the visual segment due to cockpit downward vision angle (the angle measured between a line horizontal to the surface and a line from the pilot's eye over the aircraft's nose). In most aircraft of the transport category, this angle is approximately 14°, which means at decision height, 400 feet of the visual segment will be hidden by the nose of the aircraft ($100 \div \tan 14^{\circ}$ = approximately 400 feet). The pilot's visual segment, then, will not be 1200 feet at decision height, but 800 feet. This is the segment available at decision height which the pilot must use to evaluate his approach progress and make his landing or go-around decision. A visual segment of 800 feet is insufficient to consider as visual conditions, so the aircraft must be flown by instruments below decision height. Again, cockpit geometry dictates that one pilot is necessary to maintain instrument approach progress.

The third item for consideration is the approach geometry. At decision height with 1200 feet RVR, the runway environment (runway surface touchdown zone, and centerline lights, markings, threshold

and edge lights) and the pilot's aiming or touchdown point are not in view. This means instrument flight must be continued to some altitude below decision height. At fifty feet altitude, the aircraft should be at threshold and the pilot's visual segment is approximately 1000 feet ($50 \div \tan 14^{\circ}$ = approximately 200 feet) due to the downward vision cutoff angle. Thus, a visual pilot still cannot see his aiming or touchdown point, although there should be sufficient visual references for lateral alignment and control. However, there are marginal references for longitudinal path control.

A solution to the crew procedures question would be to assign one pilot the responsibility for visual decisions and the other for instrument flight. As visual references become available, the visual pilot could use verbal cues to alert the instrument pilot about their identity, magnitude, and utility. In this manner instrument flight can be maintained to touchdown, confidence is instilled in the instrument pilot as he receives information relating to the visual environment. Also important, control integrity would not be sacrificed if a missed approach is necessary at or below decision height. To complement this crew concept, the visual pilot could assist as the visual environment allows, first in the lateral axis, then in the longitudinal axis and then take complete control at touchdown for the rollout and taxi.

The crew's roles should surely include the total integration of their efforts along with the unburdening aspects of an automatic flight control system with a flare and landing capability. Theoretically, it would seem plausible, if not absolutely essential, to assume that both pilots should have at their disposal the flight control/display systems to singly or dually accomplish flight to touchdown solely with instrumentation. The basic act of aircraft control seems somewhat trivial, but the prerogative of command should ideally rest with the aircraft commander. The aircraft commander should be the decision maker while the other pilot is responsible for instrument flight. If a fault warning system is not included in the system's design, consideration should be given towards a third pilot performing this function.

The aircraft commander would normally be the overseer for the entire flight, directing the efforts of the crew, assigning duties and making critical decisions. In the case of the low visibility landing, the aircraft commander would assume a visual posture at some predetermined altitude, evaluate the visual environment and make the

land or go-around decision. Since he would have access to the visual environment, he could assist with path control when able, or monitor the co-pilot during the entire approach and touchdown.

The instrument pilot would execute physical authority over the automatic flight control system (AFCS), assisting in the tracking function by inserting control inputs as necessary. His primary function would be the overt management of the AFCS through control inputs and selection of the proper automatic modes during the approach.

Until passing the final approach fix it is anticipated the aircraft commander would direct, at his discretion, the accomplishment of communications and aircraft configuration procedures. However, once the final approach fix is passed, the aircraft should be in its landing configuration (to prevent instability problems on short final), and the visual pilot should assume full responsibility for radio communications. The reason for this assignment is two-fold. The visual pilot, since he is the overseer for the approach, would be alert to the total situation, both inside and outside the aircraft. This also permits the instrument pilot to concentrate on systems performance, assessing the need for control inputs, and exercising proper control over the automatic system without distraction.

Since the visual pilot is alert to the geometry of the approach profile and the status of the ground environment, he should naturally assume the role of the decision maker. In his role of decision maker, he would be responsible for the land or go-around decision and also for conveying information regarding the approach to the pilot flying the instrument approach. This concept was found extremely important during the LWMI and may have merit during low visibility landings. The following verbal procedures were used during the LWMI. The first call was "CUE", which meant that portions of the runway environment were coming into view, but insufficient visual information was available to control the aircraft. The second call was "LATERAL", meaning that the visual cues were sufficient to laterally align the aircraft with the runway centerline; however, insufficient visual information was available to flare the aircraft. Also, at the lateral command, the visual pilot exercised his prerogative and assisted with lateral axis control. It is extremely important to stress at this point that there was no transfer of aircraft control and the instrument pilot was still tasked to maintain instrument flight. When

the visual pilot had sufficient references to visually control the aircraft he called, "VISUAL". At this time he could, at his discretion, aid with aircraft control with inputs into both the lateral and longitudinal axes. There was still no transfer of control. If the visual pilot wished to take complete control, he would state, "I have the aircraft", and assume complete control while the instrument pilot relinquished complete authority. It was anticipated that this command would be executed by the visual pilot only after the aircraft was safely on the runway, at which time he would assume active control for the rollout. The instrument pilot would then be responsible for configuring the aircraft for the rollout.

Another important decision that must be made is whether or not to execute a go-around. This decision should be made by the visual pilot and executed by the instrument pilot on the verbal command, "GO-AROUND". The roles of the pilots should be exact and specific as the go-around is commanded. The instrument pilot should execute the maneuver since he has physical control of the aircraft. The visual pilot would be evaluating the weather environment on final approach and hence direct the appropriate command. When a go-around is made, the visual pilot reconfigures the aircraft, leaving the other pilot free to concentrate on the go-around maneuver. Again, the main principle is to unburden the aircraft commander, who would normally be the decision maker and visual pilot, while eliminating any transfer of control during the final approach, flare and landing.

SECTION IV

SYSTEMS CONFIGURATION

General:

Control wheel dynamics can greatly enhance the pilot's ability to exert his will and judgment in conjunction with an automatic system. To complement the unburdening aspects of the control wheel and increase the effectiveness of the total system, mode selection and coupling functions should be configured to increase the overall efficiency of the pilot/autopilot relationship. Even greater flexibility can be obtained if consideration is given to integrating both pilots with independent controls and switching functions. In this manner redundancy plus an increased capability ar added to further the safety aspects of a low visibility approach.

It is impoitant then to consider the interrelation of crew duties to provide each pilot with a mode selection capability which accomplishes maximum utility of the autopilot loop without sacrificing control integrity or the role of either pilot. Almost certainly minimum visibility approaches will be accomplished with reference to some precision guidance system. The role of pilots, then, will be to assist the autopilot (if coupled) or maintain path control through the automatic flight control system if uncoupled.

Control Wheel Mode Selection

The control wheel, while serving to unburden the pilot, may also provide him the means to effect the desired autopilot/flight director modes in a most distinctive and natural manner. If mode selection is placed on the control wheel, maximum consideration should be given to the number of modes and their location. If too many modes are provided, mode selection may produce confusion during a critical period of flight. In addition, the location, form or manner of selection/annunciation is extremely essential to achieve safe as well as optimum management of the AFCS.

A very important consideration is the configuration of wheel mode selection for the management of the autopilot during low visibility approaches. The concept is to establish the configuration

which effectively integrates both pilots with maximum flexibility and potential while providing the unburdening qualities of the autopilot. At present it seems desirable, if not essential, to provide each pilot with a complete mode selection system and the capability to engage part or all of his flight control system with the autopilot. The autopilot should have a capability of accepting inputs from either or both systems while maintaining a fail operative feature.

Since the approach phase is the most critical of flight maneuvers, special consideration should be given to configuring the control wheel with only those operational modes essential to final approach. In this way the pilot is not burdened with deciphering a number of switches and modes and is able to direct his attention strictly to the final approach phase.

Each control wheel should have the same mode selection/annunciation arrangement and the capability of supplying any of its modes to the autopilot.

Each control wheel mode selection console should consist of the following coupling and mode selection features:

a. On each pilot's left console, from left to right, vertical velocity, heading, glide slope and localizer.

b. On each pilot's right console, from left to right, coupling switches for auto-throttle, yaw, roll and pitch axes.

c. On the pilot's left horn, from left to right, nose wheel steering select, autopilot uncouple and disconnect, lateral and longitudinal slewing selector for all modes. Below the center control switch, aircraft manual trim control. This configuration would be on the co-pilot's right horn.

d. On the pilot's right horn, airspeed/mach slewing switch; below this switch the emergency trim disconnect switch. These functions would be located on the co-pilot's left horn.

These mode selection features represent the primary functions necessary during the final approach phase. It is not necessary to integrate all modes and functions within the control wheel, as this would tend to clutter the wheel and make it unwieldy. Therefore, other modes could be selectable from side or center consoles for

navigation, climb, autopilot or letdown modes. These modes would consist of rotation/go-around, attitude hold, airspeed hold, mach hold, altitude hold, inertial nav, doppler, VOR and TACAN course modes. The display and selection of these modes could be through a console for each pilot on the center instrument panel or be presented by a multiple message display unit for each axis after selection from switches on a side console. The rotation/go-around mode selector should be located on the throttle handle most convenient to both pilots. In this manner initiation of go-around would be a more natural function, with the pilot prepared to supply throttle inputs if required.

The dual system characteristics established here could be routed to the autopilot from either system. Each system then would be an entity within itself. The logic is to provide two independent systems with the ability to drive the autopilot from either, or in some situations, combinations of both. This provides maximum potential and flexibility as redundancy is provided to the fourth degree with the addition of pilots in the system.

Mode Selection Considerations

The relationships and interactions between various modes, in addition to their physical and operational characteristics, is an important consideration during cockpit design. To illustrate the complex nature of mode and function analysis, let us investigate some of the possible alternatives of designing a heading mode and how it might function.

The heading mode could be such that when selected, it would present information relating to the pilot the actions necessary to turn to and maintain a heading either manually or automatically. Therefore, an important operational consideration is the method used to display mode selection to the pilot. If two pilots are involved, then each must have intelligence pertaining to the active mode and whether his system (assuming two systems) is functioning correctly and/or operating the automatics. Annunciation should therefore provide three basic types of information. What is the mode? Who has control? What is the level of automaticity serving the mode?

The problem is one of presenting annunciation in simple, meaningful patterns without undue redundancy and intricacy. Each of the three

previously mentioned functions could be selectable independently or possibly in some combination. From a piloting point of view it would be desirable to have one switch select a mode while also indicating the level of automaticity. This could be accomplished by a color coded push-to-engage switch which, when engaged, would light to show selection of the mode. The color could then indicate whether or not the mode was active, passive or failed. Orange could indicate the passive function where the mode is selected and an appropriate display results. Green could indicate the active function where the mode has been selected and the automatics are coupled. The color red annunciating the mode could mean a related heading component deactivation. If the mode was on and active (green), an autopilot failure would cause the mode to indicate passive since the mode is still operational with an autopilot failure. Thus the integrity of the mode is automatically maintained by the function of color coding and its status can be readily interpreted by the pilot.

Pilot/Automatics Interface Considerations

Other areas which must be considered are the interactions between the pilot(s), autopilot, and attitude stabilization system. These areas deal with the manner in which autopilot maintains the selected mode. If the pilot selects the heading mode, how will it function and the pilot use it? From experiences gained from the LWMI, it appears the heading mode should be configured to maintain an exact heading reference in either the attitude stabilized or coupled mode. When a pilot input is made to change the heading reference, the flight director bank command steering symbol should direct the proper direction and angle of bank for the change in heading. Also, the heading marker should deflect to the selected heading. If coupled, the aircraft should turn to the selected heading at the most desirable roll rates. If in an attitude stabilized function, the pilot would manually turn to the selected heading by centering and keeping the steering symbol centered. Another consideration is whether a force wheel input during the coupled mode should establish a new heading reference. At present a damping input can be made, but the aircraft returns to the preset heading when the force is relieved. It is believed a force wheel input should interrupt the heading hold mode resulting in a new heading reference which would be maintained after wings level flight is attained. The system would operate in the following manner when the heading mode is coupled. A force wheel input would interrupt the heading hold circuitry after a specified

force is applied causing the aircraft to turn. The maximum bank angle would be indicated by a centered bank steering symbol once the preset maximum bank angle was established. Since a new heading reference would not be established until the wings are leveled, the heading marker would remain at the top index of the horizontal situation display indicating aircraft heading. Any angle of bank greater than the preset maximum should cause the bank steering symbol to indicate a deflection in the opposite direction, meaning a reduction of bank angle is required. This type of force wheel override would not be available during radio coupled modes such as ILS, TACAN and VOR.

There are a number of available methods that pilots can use to turn to different headings. One of these is with a heading beep system. In this system a switch on the control wheel is used to move the heading marker located on the Horizontal Situation Indicator (HSI). This switch moves the heading marker 1^{o} with each depression. If held for more than 3 seconds, the heading marker slews until the switch is released. A subject for investigation would be a $1/2^{o}$ heading change with each use of the switch. If the heading mode were selected, heading would be annunciated and the bank steering symbol would be deflected in the direction to turn. The pilot has appropriate displays to turn to the new heading manually or, if coupled, the autopilot centers the bank steering bar to turn to the heading. Three important points are significant in this control configuration. First, the pilot is active in the control loop; second, the pilot is unburdened through the use of automatics; and third, the proper control/display relationships exist to assess autopilot performance. It is this third point which is extremely important and often neglected in the man-machine interface.

Other methods of turning to headings are by use of force wheel steering, the turn control knob and heading selector knob (when coupled) located on the HSI. Force wheel steering is unburdening, but requires pilot participation for the roll in and out and monitoring of bank angles and lead point. Therefore, this particular method is not as unburdening as the heading beep/coupled function previously discussed. However, it does actively involve the pilot in the control loop while providing significant unburdening. The turn control knob has been an autopilot standard for many years. This device allows pilots to establish a turn while maintaining an appropriate bank angle. The pilot then uses the turn control knob to roll out on the desired heading. This system is unburdening, but does not involve the pilot

in the control loop or establish an optimum man-machine interface.

As one can imagine, there are numerous methods to configure a heading mode. Perhaps an ideal system should include all the previously mentioned functions. In this manner sufficient redundancy would be established to satisfy any piloting requirement. As a bare minimum, a heading system should include a heading beep/coupled and force wheel turning functions.

A controversy which occurs when considering dual piloted aircraft is the configuration of the aircraft commander's system. Should his system have a built in override feature? That is, if the co-pilot is flying the aircraft in the heading mode and the aircraft is coupled to the autopilot, should the aircraft commander be able to override the co-pilot by coupling his system to the autopilot? This type of override allows the aircraft commander to assume control at his prerogative without communicating with the co-pilot or uncoupling the co-pilot's system. To the author, this type of stipulation on systems design is unwarranted.

Possibly one other facet of mode and function format should be discussed. This facet deals with the interactions of various modes. For example, when switching from a heading mode to any other lateral mode, should the mode change if incompatibilities or failures exist? One way to treat these switching arrangements is to have the mode change, but require the new mode annunciated as either passive or failed, whichever the case. In this manner pilots have received information on the status of the new mode even though it may not function. The autopilot would assume an attitude stabilized mode maintaining the last pitch and bank attitudes established. Other considerations should include the operational dynamics during switching and maximum/minimum limits during mode operation

Avionics

To complement systems development and provide precision parameters for pilot and autopilot use, the flight director computer should be a critical item and the focal point of systems design. It should accept the parameters from the Central Air Data Computer (CADC), Flight Path Angle (FPA), inertial systems and radios for presentation on the command steering bars while the flight instruments present path and performance information. The autopilot

should have the capability to be coupled directly to the command steering bars to react to computed information while the pilot possesses the means to assess automatic performance. He can determine autopilot operation from the relationship of command steering and raw information while assessing aircraft performance from the instrument displays.

The design should include two independent systems with some model and comparator circuits and the capability of injecting computed information into a fail operative autopilot (see Avionics System Schematic).

Each system should consist of at least the following components:

a. FPA computer

b. Radar altimeter

c. CADC

d. VOR/ILS radios

e. TACAN receiver

f. Compass system

g. Vertical gyro

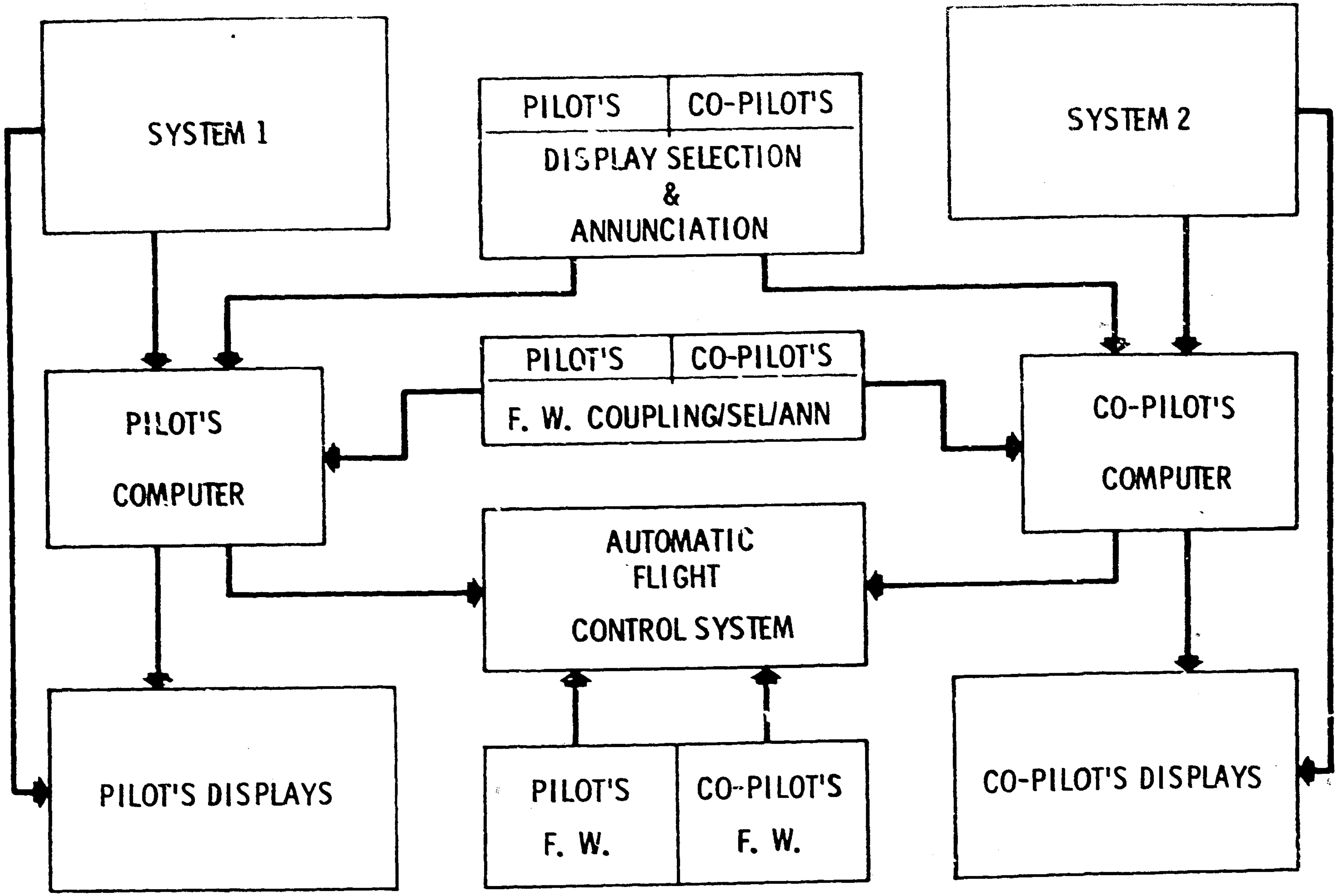
h. Mode selection/annunciation

i. Flight director computer

j. Inertial navigation system

Common components should consist of UHF, VHF receivers, fail operative FWS, autopilot and auto-throttles.

A complete avionics system must possess an independent monitor system to help the pilot assess aircraft performance. This system should be separate in every detail from the guidance being used by the instrument landing pilot and serve to either confirm or deny acceptable tracking performance.



Avionics System Schematic

SECTION V

SUMMARY

As the aviation community moves closer to establishing requirements for operations in the low visibility environment, it becomes increasingly evident that pilot/aircraft interface and crew procedures must receive considerable attention. Some of the basic problems associated with low visibility approaches can be traced to doubts concerning piloting roles when operating to lower minimums. Somewhat dependent on piloting procedures are the avionics and mode selection configurations which will not only integrate man and automatics, but provide the apparatus for control/monitoring and decision making.

When most people think of low visibility approaches and landings, autopilots usually receive the major portion of systems consideration. It is quite correct that an autopilot is an extremely important systems component. However, an autopilot in itself will not fulfill piloting requirements. What if the autopilot fails or softens in an axis? The crew must be prepared to take over the failed or softened component. This will only be possible if an adequate man/machine interface has been accomplished. In the final analysis the integrity of the total system, man/automatics and machine, must be able to survive with the total loss of all automaticity.